

Fishery Data Series No. 98-21

Stock Assessment of Arctic Grayling in Piledriver Slough During 1997

by

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September 1998

Alaska Department of Fish and Game

Division of Sport Fish



Symbols and Abbreviations

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Weights and measures (metric)		General		Mathematics, statistics, fisheries	
centimeter	cm	All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.	alternate hypothesis	H _A
deciliter	dL	All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.	base of natural logarithm	e
gram	g	and	&	catch per unit effort	CPUE
hectare	ha	at	@	coefficient of variation	CV
kilogram	kg	Compass directions:		common test statistics	F, t, χ^2 , etc.
kilometer	km	east	E	confidence interval	C.I.
liter	L	north	N	correlation coefficient	R (multiple)
meter	m	south	S	correlation coefficient	r (simple)
metric ton	mt	west	W	covariance	cov
milliliter	ml	Copyright	©	degree (angular or temperature)	°
millimeter	mm	Corporate suffixes:		degrees of freedom	df
Weights and measures (English)		Company	Co.	divided by	÷ or / (in equations)
cubic feet per second	ft ³ /s	Corporation	Corp.	equals	=
foot	ft	Incorporated	Inc.	expected value	E
gallon	gal	Limited	Ltd.	fork length	FL
inch	in	et alii (and other people)	et al.	greater than	>
mile	mi	et cetera (and so forth)	etc.	greater than or equal to	≥
ounce	oz	exempli gratia (for example)	e.g.,	harvest per unit effort	HPUE
pound	lb	id est (that is)	i.e.,	less than	<
quart	qt	latitude or longitude	lat. or long.	less than or equal to	≤
yard	yd	monetary symbols (U.S.)	\$, ¢	logarithm (natural)	ln
Spell out acre and ton.		months (tables and figures): first three letters	Jan,...,Dec	logarithm (base 10)	log
Time and temperature		number (before a number)	# (e.g., #10)	logarithm (specify base)	log ₂ , etc.
day	d	pounds (after a number)	# (e.g., 10#)	mideye-to-fork	MEF
degrees Celsius	°C	registered trademark	®	minute (angular)	'
degrees Fahrenheit	°F	trademark	™	multiplied by	x
hour (spell out for 24-hour clock)	h	United States (adjective)	U.S.	not significant	NS
minute	min	United States of America (noun)	USA	null hypothesis	H ₀
second	s	U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)	percent	%
Spell out year, month, and week.				probability	P
Physics and chemistry				probability of a type I error (rejection of the null hypothesis when true)	α
all atomic symbols				probability of a type II error (acceptance of the null hypothesis when false)	β
alternating current	AC			second (angular)	"
ampere	A			standard deviation	SD
calorie	cal			standard error	SE
direct current	DC			standard length	SL
hertz	Hz			total length	TL
horsepower	hp			variance	Var
hydrogen ion activity	pH				
parts per million	ppm				
parts per thousand	ppt, ‰				
volts	V				
watts	W				

FISHERY DATA SERIES NO. 98-21

**STOCK ASSESSMENT OF ARCTIC GRAYLING IN
PILEDRIER SLOUGH DURING 1997**

by

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ABSTRACT

In 1997, a mark-recapture investigation was conducted to assess Arctic grayling *Thymallus arcticus* in Piledriver Slough, near Fairbanks, Alaska. The timing of the investigation corresponded to the period following spring breakup of the slough, at the time of spawning. A total of 820 Arctic grayling were captured with backpack electrofishing and hook-and-line gears, marked, and subsequently released between May 12-16. Following a seven-day sampling hiatus, 994 Arctic grayling were captured using the same methods, in the same areas, and examined for marks, yielding 151 recaptures. An estimated 8,660 (SE = 1,202) Arctic grayling ≥ 150 mm FL were present during the sampling period. The 1997 stock was characterized by a high proportion age-4 and age-5 fish. Densities of Arctic grayling have continued to remain at high levels (627 fish per km), even though beaver dams have blocked migrations to headwater areas and reduced the total area of habitat by as much as 52% for the past five years and may have lowered the population carrying capacity. The estimated survival between 1996 and 1997 was 57%, which indicates the catch-and-release regulation imposed since 1993 may have lowered the overall annual mortality levels. Exploitation was estimated from estimates of catches and probability of hooking mortality and ranged up to 18%, which supports catch-and-release regulations.

Key words: Arctic grayling, *Thymallus arcticus*, Piledriver Slough, abundance estimation, age composition, size composition, spawning stock, beaver dams, survival, natural mortality, catch-and release.

INTRODUCTION

Arctic grayling *Thymallus arcticus* and other fish species common to interior Alaska colonized Piledriver Slough (Timmons and Clark 1991) after its establishment as a clearwater slough in 1976. At this time a flood control project consisting of several small dykes blocked inputs of silty, glacial water from the Tanana River. Subsequently, clear water entered approximately 45 km of the slough by upwelling from the Tanana aquifer. It is likely that Arctic grayling straying from area streams and rivers colonized Piledriver Slough. Limited information on the movements of tagged fish has suggested donor stocks were from the adjoining Moose and French creeks (Figure 1; Fleming 1991), and the more distant Chena and Salcha rivers. In the ensuing years, Arctic grayling populated the slough at higher densities than other assessed Tanana River drainage populations (Fleming 1991). Hydrologically, the slough is unlike spring-fed and rapid run-off streams and rivers in the area. Water temperature at Piledriver Slough fluctuates substantially through the season and throughout the day (Fleming 1995), unlike spring-fed streams such as the Delta Clearwater River (Wojcik 1955, Tack 1980). The combination of nearly-constant flow, low velocity (low gradient), and the generally early spring breakup and warming has created suitable habitat for Arctic grayling spawning, rearing, and feeding.

Since 1987, Piledriver Slough has been stocked with rainbow trout *Oncorhynchus mykiss* to provide stream fishing opportunities close to Fairbanks. Prior to the stocking program, Piledriver Slough received between 1 and 3% of the total Tanana drainage effort in angler-days (Table 1). Since the 1987 inception of the rainbow trout stocking program, fishing effort in Piledriver Slough increased by as much as five-fold, and in 1990 it received approximately 15% of the fishing effort within the Tanana River drainage (Mills 1991). The fishery provided as much as 20% of the total Arctic grayling catches in the Tanana River drainage during 1990 and 1991 (Mills 1991, 1992) and as much as 16% of the drainage harvest of rainbow trout in 1988 (Mills 1989).

The popularity of the fisheries at Piledriver Slough indicated a need for annual stock assessment of Arctic grayling to ensure sustainable harvests. A stock assessment program was initiated in

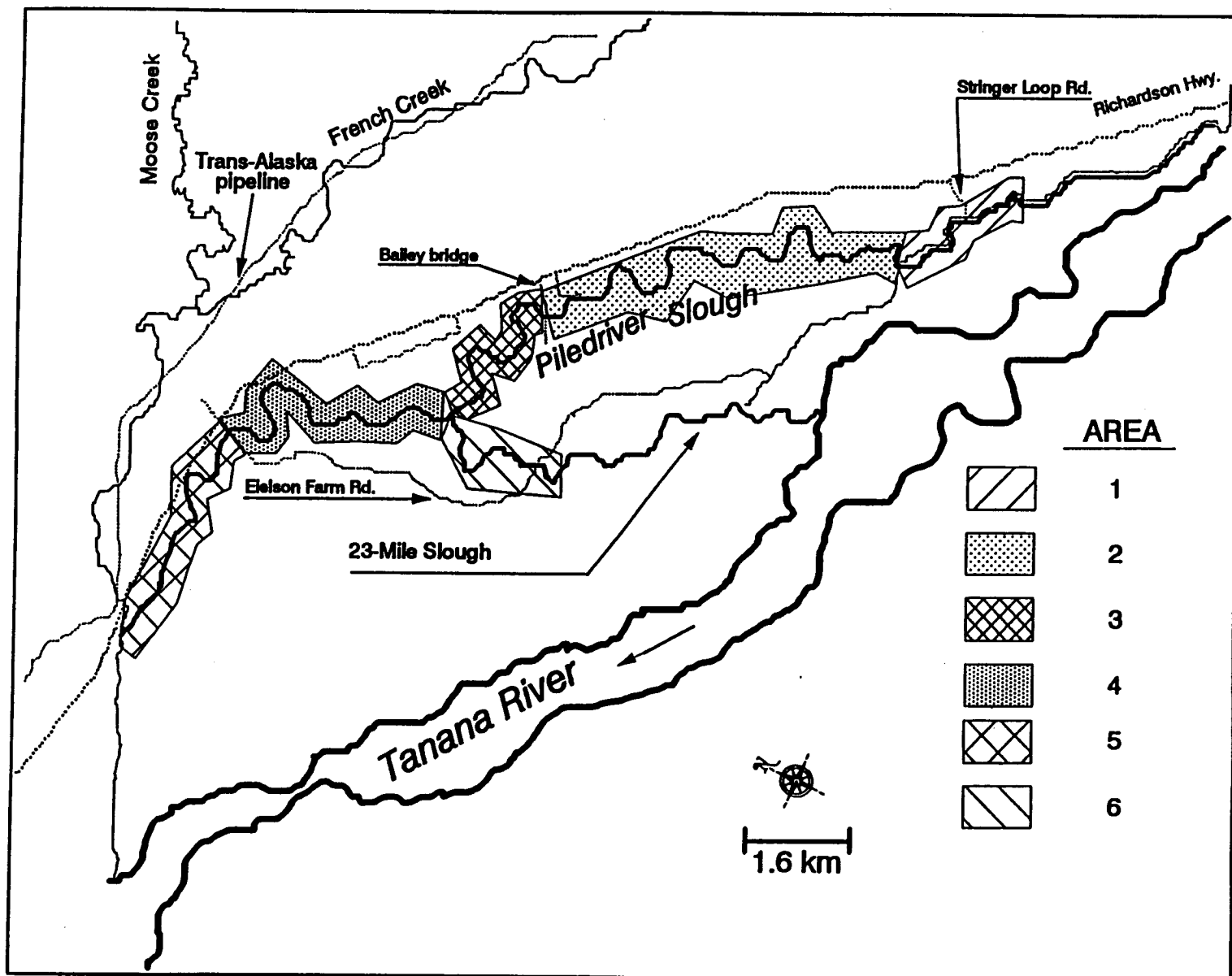


Figure 1.-Piledriver Slough and adjoining creeks and rivers.

Table 1.-Effort, catch, and harvest of Arctic grayling from Piledriver Slough and the Tanana River drainage, 1983 to 1996^a.

Year	Piledriver Slough			Tanana River Drainage			% Tanana River Drainage ^b		
	Days Fished	Catch	Harvest	Days Fished	Catch	Harvest	Days Fished	Catch	Harvest
1983 ^c	4,148	N/A	5,822	144,981	N/A	91,682	2.8	N/A	6.3
1984 ^d	4,651	N/A	3,751	145,142	N/A	82,548	3.2	N/A	4.5
1985 ^d	2,133	N/A	2,133	135,745	N/A	62,433	1.6	N/A	3.4
1986 ^d	2,079	N/A	2,312	144,814	N/A	45,780	1.4	N/A	5.0
1987 ^e	13,247	N/A	4,907	155,346	N/A	38,230	8.5	N/A	12.8
1988 ^f	24,375	N/A	8,095	173,706	N/A	51,803	14.0	N/A	15.6
1989 ^g	22,746	N/A	4,459	185,715	N/A	53,791	12.2	N/A	8.3
1990 ^h	27,705	34,840	2,380	184,887	171,058	28,414	14.9	20.4	8.4
1991 ⁱ	17,703	30,012	3,987	155,662	146,892	33,778	11.4	20.4	11.8
1992 ^j	13,607	15,252	1,030	120,848	115,633	14,983	11.3	13.2	6.9
1993 ^k	17,263	32,036	759	160,117	193,088	17,658	10.8	16.6	4.3
1994 ^l	11,369	31,324	57	148,633	243,906	24,741	7.6	12.8	0.1
1995 ^m	12,613	17,431	0	201,389	156,611	16,089	6.2	11.1	0.0
1996 ⁿ	11,736	16,667	0	203,962	172,302	11,334	5.7	9.6	0.0

^a Statewide harvest estimates for Arctic grayling in Piledriver Slough began with the 1983 fishery.

^b Percent of Tanana River drainage fishery represented by Piledriver Slough.

^c Mills 1984.

^d Mills, unpublished data *taken from* Timmons 1992.

^e Mills 1988.

^f Mills 1989.

^g Mills 1990.

^h Mills 1991.

ⁱ Mills 1992.

^j Mills 1993.

^k Mills 1994.

^l Howe et al. 1995.

^m Howe et al. 1996.

ⁿ Howe et al. 1997.

1990 to characterize the Arctic grayling stock in Piledriver Slough and adjoining watersheds (Timmons and Clark 1991). Initially, spring assessments occurred within all portions of Piledriver Slough that were accessible to Arctic grayling. In 1990 and 1991, assessment included between 31 and 34 km of the slough. In these two years, the assessments were extended downstream 5.8 km below the Eielson Farm Road (Timmons and Clark 1991, Fleming 1991). Sampling was discontinued in this area in 1992 because few Arctic grayling were sampled there, and it was concluded that this was not important spring habitat. During the summer of 1991, beavers began creating dams in the headwater areas that prevented fish passage. In May 1992, several large beaver dams prevented the upstream migration by Arctic grayling into 12.7 km of habitat in headwater areas. Between the 1994 and 1996 assessments, several additional beaver dams were constructed, which blocked off an additional 2.3 km. Of the original habitat utilized by Arctic grayling in spring and summer of 1990 and 1991, approximately 48% remains.

Spring abundances of Arctic grayling peaked in 1991, and since then a declining trend in abundance of Arctic grayling ≥ 150 mm FL has been indicated by assessment results:

Assessment Year (source)	Estimated Abundance	Standard Error
1990 (Timmons and Clark 1991)	16,435	1,396
1991 (Fleming 1991)	17,323	869
1992 (Fleming and Schisler 1993)	14,030	1,860
1993 (Fleming 1994)	10,587	1,351
1994 (Fleming 1995)	11,747	1,297
1996 (Fleming 1997)	9,981	1,256

The decline in abundance led to a catch-and-release angling regulation by emergency order on June 26, 1993.

In 1995, the stock was not assessed after findings from 1994 indicated signs of stock rebuilding. Estimates of angling effort and catches (Howe et al. 1996) indicated a low level fishery occurred in 1995. In 1996, further declines in the assessed stock were indicated after nearly three seasons of catch-and-release angling regulations.

Stock assessment was planned for 1997 given several concerns, which included the continued decline of abundance, the significant loss of habitat, and the upcoming Alaska Board of Fisheries action on a proposal to codify Arctic grayling regulations at Piledriver Slough to catch-and-release fishing only.

OBJECTIVES

The research objectives for 1997 were to:

1. estimate abundance of Arctic grayling ≥ 150 mm fork length (FL) in a 13.8 km section of Piledriver Slough;
2. estimate age composition of Arctic grayling in Piledriver Slough; and,
3. estimate size composition of Arctic grayling in Piledriver Slough.

In addition to these objectives, survival, mortality, and exploitation parameters were estimated for the stock(s) present in 1996 and 1997, at Piledriver Slough.

METHODS

SAMPLING

In 1997, the study area comprised a 13.8 km section of Piledriver Slough (Figure 2) that was accessible to Arctic grayling. The study area was divided into three sections delineated by landmarks, access points, or one crew-day's coverage (Fleming 1991). The sections of Piledriver Slough examined during 1997 are described as follows (from Fleming 1991):

- Section {2} Culverts to Bailey Bridge. This section of Piledriver Slough is a remote section, accessible from either end. The stream is generally small with alternating pools, riffles, and minor braiding. The downstream portion of this section also includes long runs and larger pools.
- Section {3} Bailey Bridge to 23-Mile Slough. This section is easily accessed by a road and a path, respectively. In this section, a habitat transition occurs; the variability seen in the upstream area is reduced. This section is generally wide and slow moving, with increased water volume.
- Section {4} 23-Mile Slough to Eielson Farm Road. The water throughout this section is easily accessed by a path and a road, respectively. This section is primarily broad and slow, with some deep pools and few riffle areas.

Since 1992, assessments were discontinued in several headwater segments comprising 21 km of Piledriver Slough (sections {1}, {6} and part of {2}), owing to several unbreached beaver dams (Figure 1). No fish were located upstream of the blockages during foot and canoe surveys. The upstream limit of fish distribution and the 1997 study area boundary was located at a new unbreached beaver dam, 13.8 km above the Eielson Farm Road crossing (Figure 2). The downstream sampling boundary was at the Eielson Farm Road crossing (Figure 2).

Sampling began on May 12 and finished on May 23, 1997. Two five-day sampling events were completed by a single six-person crew using electrofishing, and hook-and-line sampling. Each sampling event began at the upstream boundary and was conducted systematically downstream to the lower study area boundary. The backpack electrofishing techniques were identical to previous assessments (Timmons and Clark 1991, Fleming 1991, Fleming and Schisler 1993, Fleming 1994, Fleming 1997). Similar to 1996, block-nets (10 m beach seines composed of 20 mm braided mesh) were used to increase capture efficiency. First, two crew members proceeded downstream of the electrofishing crew and stretched the net across the channel, in the tail-out areas of pools. After the block-net was in place, the electrofishing crew, spread laterally across the slough channel, fished downstream towards the net. Hook-and-line sampling gear also supplemented the electrofishing gear in 1997. This gear type was used by the same crew in an area where many fish were present but could not be captured by electrofishing in the deep water.

All captured Arctic grayling were dipped from the water, measured to the nearest 1 mm FL, and fish ≥ 150 mm FL were examined for finclips and tags. Fish captured during the first sampling

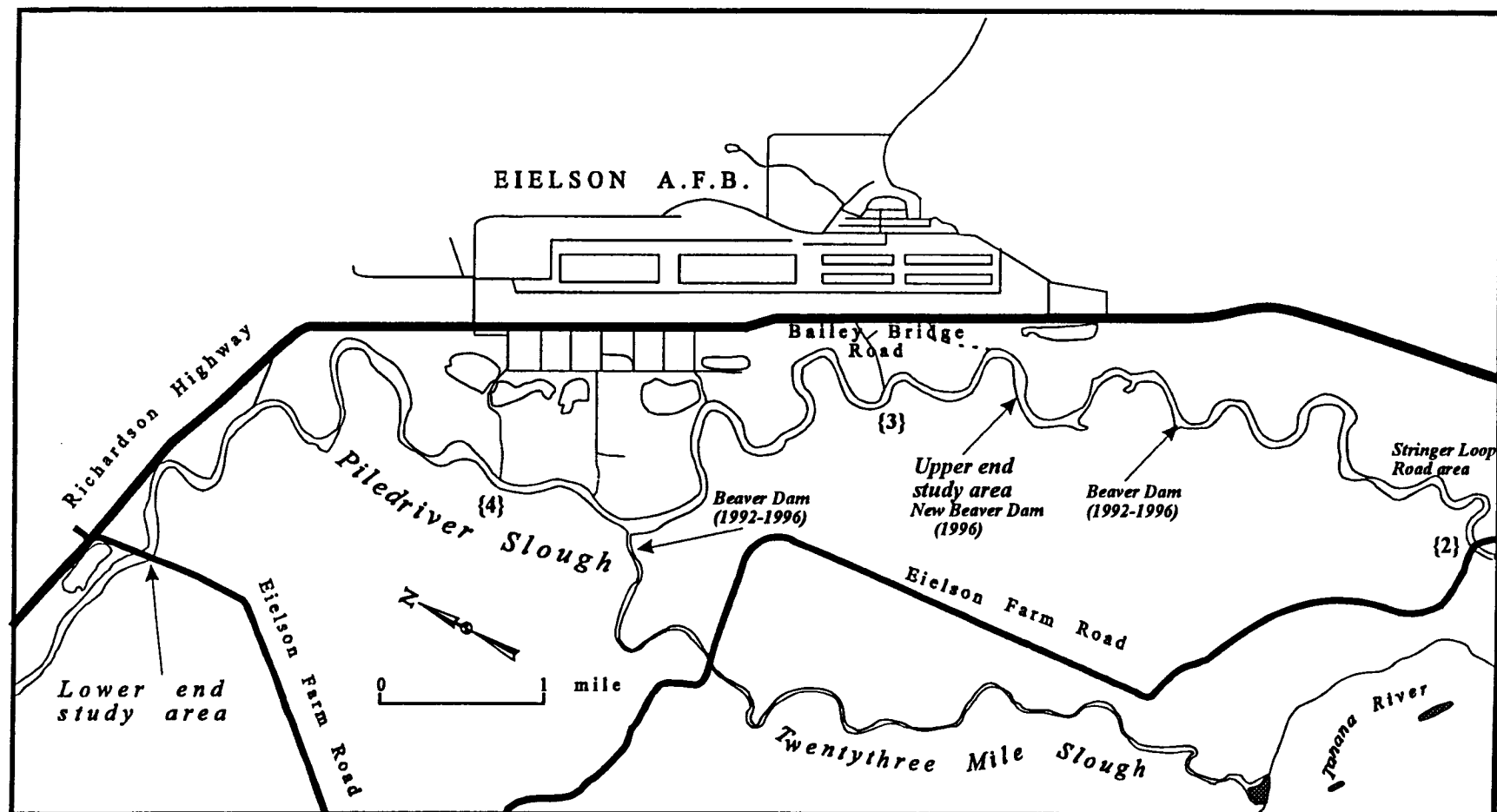


Figure 2.-Map of the Piledriver Slough study area during 1997 (numbers in brackets represent upstream delineation of sampling sections). Beaver dams are dated for the years when they first impaired annual migration and distribution.

event were examined for previous tags and marks, given an upper caudal finclip, tagged with an individually numbered Floy™ FD-67 internal anchor tag, and released. Fish captured during the second sampling event were inspected for primary marks, given a lower caudal finclip, and released. The new tags deployed in 1997 were gray and tag numbers ranged between 68,000 and 68,766. Scales were collected from all fish during the second sampling event for later aging. Scales were taken from the left flank area approximately six scale rows above the lateral line, second down from the posterior insertion of the dorsal fin (W. Ridder, Alaska Department of Fish and Game, Delta Junction, unpublished information on refinement of methods described by Brown 1943). Two scales from each fish were briefly cleaned, then mounted directly on gum cards. Fork length, finclips, and tag numbers were recorded on Tagging-Length forms (Version 1.0). Data collection procedures from previously marked Arctic grayling were similar, but previous tag numbers, and colors were also recorded.

Following the field investigation, the gum cards were used to make triacetate impressions of the scales for aging using a heated hydraulic press (30 s at 137,895 kilopascals, at a temperature of 97°C). Ages were later determined by counting annuli from acetate impressions of scales magnified to 40X with the aid of a microfiche reader. Criteria for determining the presence of an annulus were: 1) complete circuli cutting over incomplete circuli; 2) clear areas or irregularities in circuli along the anterior and posterior fields; and, 3) regions of closely spaced circuli followed by a region of widely spaced circuli (Kruse 1959).

ABUNDANCE ESTIMATION

A closed-model mark-recapture experiment was used to estimate the abundance of Arctic grayling in Piledriver Slough in 1997, similar to approaches used in 1991, 1992, 1993, 1994, and 1996. The use of a closed-model mark-recapture abundance estimator assumes the following (Seber 1982):

1. the population in the study area must be closed, i.e. the effects of migration, mortality, and recruitment are negligible;
2. all Arctic grayling have the same probability of capture during the first sample or in the second sample or marked and unmarked Arctic grayling mix completely between the first and second samples;
3. marking of Arctic grayling does not affect their probability of capture in the second sample, and;
4. Arctic grayling do not lose their mark between the first and second sampling events.

Assumption 1 could not be fully validated because of past variation in migration patterns of Arctic grayling with respect to the time and area of stock assessment. In 1994, a picket weir was used in the mark-recapture assessment of Arctic grayling in Piledriver Slough (Fleming 1995). During the 51 days of operation (April 12-June 2, 1994) only 8% (933 fish) of the estimated stock size immigrated and 3.8% (447 fish) emigrated from the study area. Approximately 90% of the stock was determined to have entered the slough prior to the set-up of the weir on April 12, 1994. In 1996, the perceived migration patterns into the study area were contrary to 1994 findings. Following a winter of unusually low precipitation and exceptionally thick aufeis accumulation, the immigration of Arctic grayling was substantially later. At the completion of

the second of three sampling passes (May 30, 1996), approximately 66% of the assessed stock was present (unpublished data) and schools of smaller Arctic grayling were seen migrating into the study area (Fleming 1997). To examine for potential bias introduced by immigration in 1997, marked-to-unmarked ratios and size compositions were examined in the lower sampling sections to detect dilution of marks by an influx of unmarked fish, or by a significant shift in size composition. To examine for potential bias introduced by emigration, size compositions of the marked and recaptured Arctic grayling were inspected for shifts that would suggest larger (post-spawning fish) were not present during the second sampling event.

Assumptions 2 and 3 were examined by testing for differences in capture probability by gear type, geographic area, and by size. Gear type and spatial differences in capture probability were evaluated through examination of recapture-to-catch ratios by gear type (electrofishing and hook-and-line gears) and the geographic areas (sampling area). Results of chi-square statistical tests were used to determine whether abundance estimation should initially be stratified by gear type or area. The existence of size selectivity within the mark-recapture experiment was determined by the outcome of two Kolmogorov-Smirnov (KS) two-sample tests. The first KS test compared the cumulative length frequency distributions of marked and recaptured Arctic grayling. The second KS test compared cumulative length frequency distributions of Arctic grayling from the first (mark event) and second (recapture event) samples. The results of the KS tests also suggested the methods required to alleviate size biases (Appendix A1). Assumption 4 was satisfied by double marking fish in the first sampling event with individual tags and easily identified finclips that could not be shed during the study.

Capture probabilities did not vary by gear type, but varied significantly between sampled areas. Additionally, the movement by marked fish between sampling sections was significant, and the mixing of marked and unmarked fish was not complete (uniform). Because of this, the first part of the abundance estimation framework in 1997 was to choose the most appropriate estimator. This was accomplished through the following steps:

1. calculate separate population estimates for each resulting stratum (area) and sum the resulting independent estimates to produce an overall estimate of abundance;
2. calculate a maximum likelihood estimate of abundance for the partially stratified Darroch model (Darroch 1961); and,
3. compare results of the two estimators and if the estimates were dissimilar (either a statistically significant difference or a biologically meaningful difference exists), select the partially stratified (Darroch) approach as the relevant method.

Before proceeding with abundance estimation the next step was to determine the extent of size selectivity with regards to the mark-recapture experiment. The two KS tests indicated that there was size-selectivity during both sampling events (Appendix A1: Case III), which led to an examination for additional stratification by size grouping. This was accomplished by partitioning the data into size strata. To maximize the difference in capture probability between size strata, a series of chi-squared tests were used to evaluate optimum strata break points. The length at stratification that produced the largest chi-squared test statistic was used to delimit the size strata.

Abundance of Arctic grayling was first estimated using the modified Petersen estimator of Bailey (1951, 1952). Bailey's modification was used because of the systematic sampling approach and

the level of mixing (localized, not complete; Seber 1982) of marked and unmarked fish over the length of the sampling area (Seber 1982). Stratified estimates of abundance for each stratum were calculated as:

$$\hat{N}_i = \frac{n_{1i}(n_{2i} + 1)}{(m_{2i} + 1)} \quad (1)$$

where:

- \hat{N}_i = the abundance of Arctic grayling (≥ 150 mm FL) in area stratum i ;
- n_{1i} = the number of Arctic grayling marked and released during the first event;
- n_{2i} = the number of Arctic grayling examined for marks during the second event; and,
- m_{2i} = the number of Arctic grayling recaptured in the second event.

Variance of this estimator was calculated by (Bailey 1951, 1952):

$$\hat{V}[\hat{N}_i] = \frac{(n_{1i})^2(n_{2i} + 1)(n_{2i} - m_{2i})}{(m_{2i} + 1)^2(m_{2i} + 2)} \quad (2)$$

The second estimation procedure utilized a partially stratified approach, which accounts for partial mixing between the sampling areas, and levels of movement which may bias results of the area-stratified estimates. The maximum likelihood estimates of parameters of the Darroch model (Darroch 1961) were found using a derivative-free search algorithm (Mike Wallendorf, ADF&G, personal communication). The variance of the estimated abundance was estimated from the observed information matrix and the delta method (Seber 1982).

AGE AND SIZE COMPOSITION

Apportionment of the estimated abundance among age or size groupings depends on the extent of sampling and behavioral biases. The outcome of chi-square tests to detect geographic differences in capture probabilities and KS tests to detect size selectivity determined the necessary adjustments. Because adjustments were required for geographic differences in capture probability and movement, the proportion of fish at age k (or length class k) was estimated using pooled sample data (Appendix A1: Case III, from both events) by:

$$\hat{p}_k = \frac{y_k}{n} \quad (3)$$

where:

- \hat{p}_k = the proportion of Arctic grayling that were age k ;
- y_k = the number of Arctic grayling sampled that were age k ; and,
- n = the total number of Arctic grayling sampled.

The unbiased variance of this proportion was estimated as:

$$\hat{V}[\hat{p}_k] = \frac{\hat{p}_k(1 - \hat{p}_k)}{n - 1} \quad (4)$$

To adjust age and size data, the proportion of fish at age is calculated by summing independent abundances for each age or size class and then dividing by the summed abundances for all age or size classes. First the conditional proportions from the sample were calculated:

$$\hat{p}_{jk} = \frac{n_{jk}}{n_j} \quad (5)$$

where:

n_j = the number sampled from area stratum j in the mark-recapture experiment;

n_{jk} = the number sampled from area stratum j that are age k ; and,

\hat{p}_{jk} = the estimated proportion of age k fish in area stratum j .

The variance calculation for \hat{p}_{jk} was identical to equation 4 (with appropriate substitutions).

The estimated abundance of age k fish in the population is then:

$$\hat{N}_k = \sum_{j=1}^S \hat{p}_{jk} \hat{N}_j \quad (6)$$

where:

N_j = the estimated abundance in area stratum j , and ;

S = the number of area strata.

The variance for \hat{N}_k in this case is approximated by the delta method (Seber 1982):

$$\hat{V}[\hat{N}_k] = \sum_{j=1}^S \left(\hat{V}[\hat{p}_{jk}] \hat{N}_j^2 + \hat{V}[\hat{N}_j] \hat{p}_{jk}^2 \right) \quad (7)$$

The estimated proportion of the population that are age k (\hat{p}_k) is then:

$$\hat{p}_k = \hat{N}_k / \hat{N} \quad (8)$$

where: $\hat{N} = \sum_{j=1}^S \hat{N}_j$

Variance of the estimated proportion can be approximated with the delta method (Seber 1982):

$$\hat{V}[\hat{p}_k] = \sum_{j=1}^S \left\{ \left(\frac{\hat{N}_j}{\hat{N}} \right)^2 \hat{V}[\hat{p}_{jk}] \right\} + \frac{\sum_{j=1}^S \{ \hat{V}[\hat{N}_j] (\hat{p}_{jk} - \hat{p}_k)^2 \}}{\hat{N}^2} \quad (9)$$

Equations 5 through 9 are also used to adjust biased size composition estimates, replacing the number sampled at age k that are also in area strata j (n_{jk}) with the number sampled per 10 mm FL incremental size category k ($k = 155, 165, 175 \dots 395$).

SURVIVAL, MORTALITY, AND EXPLOITATION

Survival was estimated as the proportion of the summed abundance from a portion of an age series at one time, that are estimated to be present at a later time (Ricker 1975). Only ages that appear to be fully recruited were used as the portion of an age series. Abundance-at-age estimates beginning in 1991 (Fleming 1991) indicated Arctic grayling age 5 years and older were fully recruited at the time and location of the stock assessment. The age at full recruitment for the present investigation was also assumed to be age 5, so that comparisons with previous estimates of survival, mortality, and exploitation (Fleming and Schisler 1993, Fleming 1994, Fleming 1995) could be made.

The annual survival rate S , was estimated as:

$$\hat{S} = \frac{\hat{N}_{t+1}}{\hat{N}_t} \quad (10)$$

where:

$$\begin{aligned} \hat{S} = \frac{\hat{N}_{t+1}}{\hat{N}_t} &= \text{the estimated proportion of Arctic grayling age 5 and up (k=5,6,7,8,9,) in year } t \text{ that survive to year } t+1 \text{ as age 6 and up (k = 6,7,8,9,10); and,} \\ \hat{N}_t &= \text{the summed estimated abundance of Arctic grayling age 5 years and up in year } t; \text{ and,} \\ \hat{N}_{t+1} &= \text{the summed estimated abundance of Arctic grayling age 6 years and up in year } t+1. \end{aligned}$$

The variance of \hat{S} was approximated with the delta method (Seber 1982) as:

$$V[S] \approx \left[\frac{N_{t+1}}{N_t} \right]^2 \left[\frac{V[N_{t+1}]}{[N_{t+1}]^2} + \frac{V[N_t]}{N_t^2} \right] \quad (11)$$

where the variance for N_t and N_{t+1} were each estimated as a sum of the exact variance of a product from Goodman (1960):

$$V[\hat{N}_t] = \sum_{k=5}^{10} (V[\hat{p}_k] \hat{N}_{96}^2 + V[\hat{N}_{96}] \hat{p}_k^2 - V[\hat{p}_k] V[\hat{N}_{96}]) \quad (12)$$

and;

$$V[\hat{N}_{t+1}] = \sum_{k=6}^{10} (V[\hat{p}_k] \hat{N}_{97}^2 + V[\hat{N}_{97}] \hat{p}_k^2 - V[\hat{p}_k] V[\hat{N}_{97}]) \quad (13)$$

where:

\hat{N}_{96} = the abundance estimate for Arctic grayling ≥ 150 mm FL in 1996; the variance of \hat{N}_{96} was from the point estimated variance from the stratified Petersen model (reported in Fleming 1997).

\hat{N}_{97} = the abundance estimate for Arctic grayling ≥ 150 mm FL in 1997; the variance of \hat{N}_{97} was from the point estimated variance from the selected abundance estimator in 1997.

\hat{p}_k = the estimated adjusted proportion of the fish in age class k from 1996 and the 1997 estimated proportions in age class k from the present study.

The annual survival rate was converted into annual and instantaneous rates of mortality with respect to the following relationships (from Ricker 1975):

- Z = the instantaneous total mortality rate;
- Z = $-\ln(S)$
- F = the instantaneous rate of fishing mortality;
- M = the instantaneous rate of natural mortality;
- Z = F + M;
- A = the annual mortality rate;
- A = $1 - e^{-Z}$, where $e \approx 2.71828$; and $A = 1 - S$

Exploitation and natural mortality rates were estimated for the assessed stock ≥ 150 mm FL. For this purpose, the survival rate estimated for fish age 5 and older was assumed to be representative and applied to the entire assessed stock. In order to apportion total instantaneous mortality (Z) among fishing (F) and natural (M) mortality components, Baranov's catch equation (Ricker 1975) was rearranged and solved for F:

$$F = \frac{Z}{A} * \frac{C}{N} \quad (14)$$

where:

C = typically the reported harvest, but with current no-harvest regulation this became the *product* of estimated catches of Arctic grayling (Howe et al. 1997) from the 1996

Piledriver Slough fishery *and* an assigned empirical probability of mortality by hooking injury;

N = the 1996 abundance estimate of Arctic grayling in Piledriver Slough;

Z = the estimated total instantaneous mortality rate calculated for apparently recruited year classes (age 5 and older). Recruited year classes were age classes whose representation (proportion or abundance) had reached a maxima.

Because catch-and-release induced mortalities are likely to be latent, and not represented in reported harvests of Arctic grayling, the expectation of natural mortality is likely biased high. To offset this, a sensitivity analysis was conducted in which additions were made to the reported harvest (0) at a level which would approximate hooking mortality. To accomplish this, the estimated catch (Howe et al. 1997) represented independent catch-and-release events in 1996. This estimate was multiplied by the incidence of hooking mortality, which was set at 0 and 9%. The bounds of the hooking mortality rate corresponded to the 95% confidence interval from a study of hooking mortality on wild Arctic grayling (Clark 1991). The product of this multiplication represented an estimate of fish that died following catch and release.

Before estimating natural mortality and exploitation parameters, a classification of the Arctic grayling fishery was needed to select estimator formulae. The two types proposed by Ricker (1975) are:

Type 1= where natural mortality occurs during a time of year other than the fishing season; the population decreases during the fishing season because of catch (harvest) removals only; or,

Type 2= where natural mortality occurs along with fishing; each occurs at a constant instantaneous rate, or the two rates vary in parallel fashion.

Based upon present insights into the basic life history for Arctic grayling, the Type 1 classification was selected. The rate of exploitation (u) estimated for a Type 1 fishery was (Ricker 1975):

$$u = 1 - e^{-F} \quad (15)$$

The expectation of natural death was estimated (Ricker 1975):

$$v = n(1-u) \quad (16)$$

where:

v = expectation or probability of natural death; and,

n = conditional rate of natural mortality, which is calculated as (from Ricker 1975): $n = 1 - e^{-M}$

RESULTS

SAMPLING

Mark-recapture sampling was conducted over 13.8 km of Piledriver Slough in May 1997 (Figure 2). In the first sampling event, the six person sampling crew captured and sampled 820 Arctic grayling (≥ 150 mm FL) of which all 766 were released as marked fish with tags and upper caudal finclips. Electrofishing was the primary capture gear and accounted for 85% (695) of the marked fish sample. Hook and line sampling gear was used after many fish were observed but were not captured by electrofishing in a portion of Area 4. In this area, the slough's depth and width prevented the electrofishing crew from capturing fish. As a result, 125 fish were sampled using small jigs, spinners, and flies. These fish were sampled using identical methods and released as marked fish. The first sampling event ran from May 12 - 16. Daily water temperatures ranged between 5° and 8°C and the low and clear water conditions were consistent with all assessment years prior to 1996. In 1996, remaining buildups of aufeis (overflow ice) created blockages and temporary flow diversions until late-May.

On May 19, the sampling crew resumed sampling after a 7-day hiatus. In the second sampling event, the crew captured and examined 994 Arctic grayling (≥ 150 mm FL) for marks over the five day period. This sample yielded the recovery of 151 marked Arctic grayling released during the marking event. Electrofishing and Hook and line sampling gears were employed in the same reaches as in the marking event, with the same amount of directed effort. Electrofishing catches included 86% (853 fish) of the total catch and yielded the recovery of 142 fish marked during the first sampling event. Hook and line sampling catches included the remaining 14% (141 fish) and yielded the recapture of nine (9) fish marked during the first sampling. The second sampling event ran from May 19 - 23. Water temperatures ranged between 7.5 ° and 12 °C. The overall acute mortality rate from mark-recapture sampling in 1997 was 4 fish out of 1,661 individual Arctic grayling handled, or 0.2%.

ABUNDANCE ESTIMATION

The use of several gear types to capture fish in the 1997 mark-recapture assessment required examination before proceeding with abundance estimation. In sampling area 4, hook and line gear was used in an area where the water depth (up to 10 feet deep) precluded effective electrofishing. Equal capture probabilities were detected when the mark-recapture data for area 4 was subdivided into three sampling sections (upper, middle, and lower), which corresponded to electrofishing, hook-and-line, and electrofishing gear types, respectively ($\chi^2 = 1.66$, $df = 2$, $P = 0.43$). The effect of gear type was further examined and found insignificant by contingency testing the release-recapture matrix ($\chi^2 = 3.33$, $df = 2$, $P = 0.19$). The effect of gear type on the sizes of collected fish was not fully examined because of the limited number of recaptured fish in the area where the gear comparisons were made. At this point, data collected by the two gear types were combined for further examinations.

Unequal probabilities of capture (recapture-to-catch rate) were detected from three different sections which comprise the 13.8 km Piledriver Slough study area ($\chi^2 = 37.2$, $df = 2$, $P = < 0.001$). During the 7-day sampling hiatus, 37 of 151 (24.5%) recovered fish had moved from their release section and partially mixed through the study area (Table 2). Similar capture

Table 2.-Numbers of marked and recaptured Arctic grayling (≥ 150 mm FL) and tabulation of catches and recaptures by area in Piledriver Slough, May 12-23, 1997.

Marking Event:		Area Recaptured:			Recovered:	
Number Marked:	Area Released:	2	3	4	Yes	No
119	2	6	18	3	27	92
435	3	2	93	11	106	329
266	4	0	3	15	18	248
Total:	820	8	114	29	Total: 151	669
	Marked (M)	8	114	29	Total: 843	
	Unmarked (U)	36	422	385	Total: 994	
	Catch	44	536	414		
	M/U Ratio	0.22	0.27	0.07		

probabilities in the upper and middle sections (0.18 and 0.21, respectively: $\chi^2 = 0.23$, $df = 1$, $P = 0.62$) allowed pooling. After pooling, two 6.9 km sections (strata) of differing capture probabilities resulted: pooled section {2, 3} and section {4} ($\chi^2 = 36.9$, $df = 1$, $P = <0.01$). The capture probabilities expressed as the marked-to-unmarked ratios, in pooled section {2, 3} were 0.21 and 0.07 in section {4}.

The KS tests on the upstream section data suggest that size selectivity was present during both sampling events (Figure 3A - mark vs recaptures: $D = 0.14$, $P = 0.04$; and, Figure 3B - mark vs catch: $D = 0.05$, $P = 0.40$). The KS tests on the downstream section data inferred that size selectivity was not present during either sampling events (Figure 4A -mark vs recaptures: $D = 0.19$, $P = 0.29$; and, Figure 4B - mark vs catch: $D = 0.07$, $P = 0.37$).

The selected size strata were: 150 to 231 mm FL, and 232 mm FL and larger. This was based on maximal differences in recapture-to-catch ratios among possible strata ($\chi^2_{231mm} = 9.62$, $df = 1$). As a result, the area-stratified abundance in the upstream section was further stratified by size groupings while the downstream section was not.

Because testing also revealed that there was incomplete mixing of marked fish among the three areas, an estimate using the Darroch movement model stratified by size was attempted. However, because only six fish were recaptured in the small fish stratum, the model could not effectively estimate abundance for small fish. Although the large fish strata included 145 recaptured fish, the Darroch model failed to successfully estimate abundance of large fish due to estimates of capture probability which were greater than one. As a result, a maximum likelihood estimate for the Darroch model was generated *using three areas and* size stratification. The final estimate of Arctic grayling (≥ 150 mm FL) using this model was 8,660 fish ($SE = 1,202$ $CV=14\%$). A comparison of this estimate to the stratified Bailey estimate (Table 3) indicated a biologically meaningful difference existed, with the MLE point estimate 35% higher. Although the MLE estimator did not allow for size stratification, the KS plots comparing the various length distributions (Figures 3-4), indicated that bias due to size-selectivity was likely negligible compared to bias associated with incomplete mixing. Therefore, the Darroch MLE estimator was chosen as the most appropriate model. The estimated density of Arctic grayling (≥ 150 mm FL) in Piledriver Slough during 1997 was 627 fish/km (Table 4).

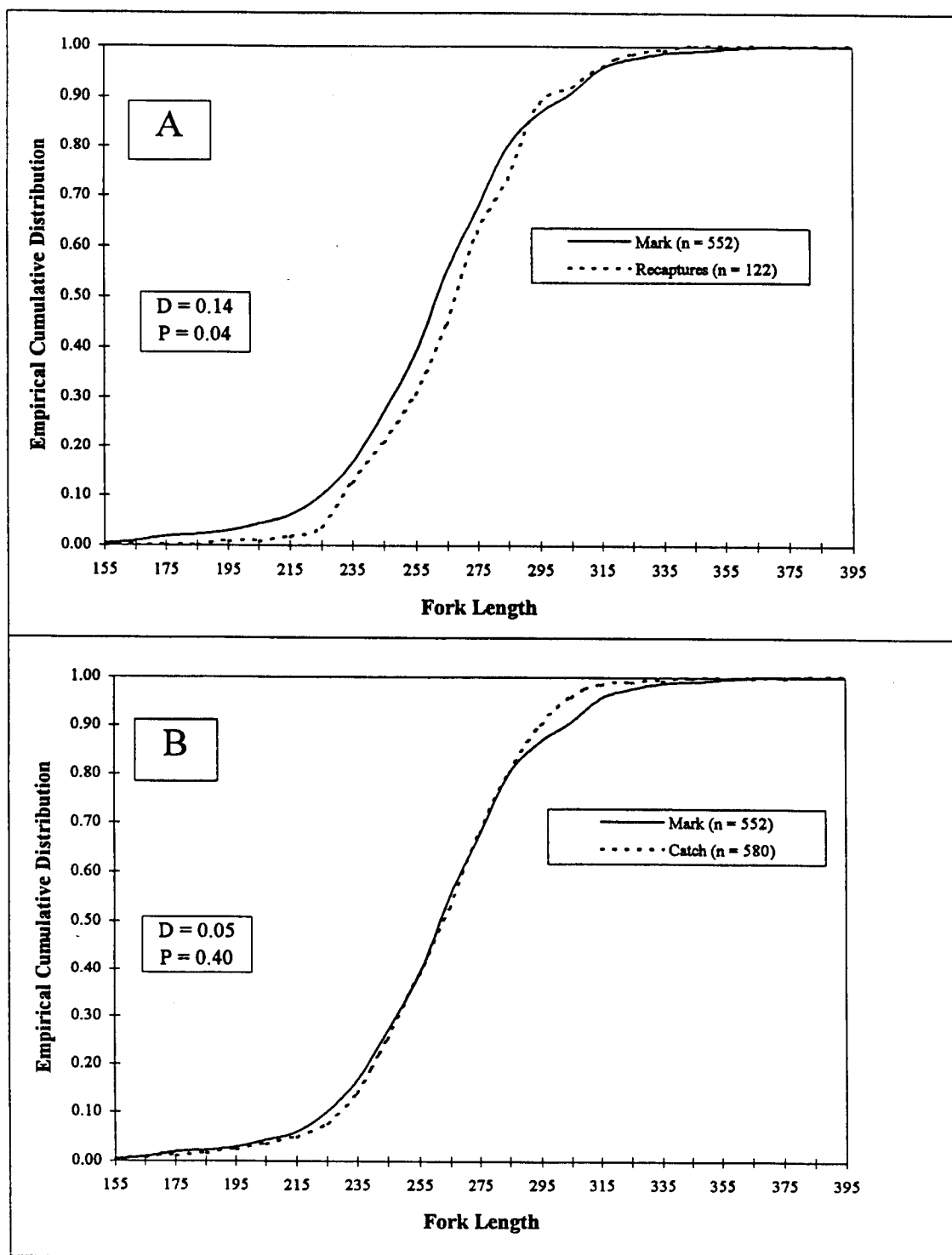


Figure 3.-Empirical cumulative distribution of lengths of Arctic grayling marked (n=552) versus lengths of Arctic grayling recaptured (n=122) in the upstream strata (A) and, versus lengths of Arctic grayling examined for marks (n=580) in the upstream strata (B) in Piledriver Slough, May 12-23, 1997.

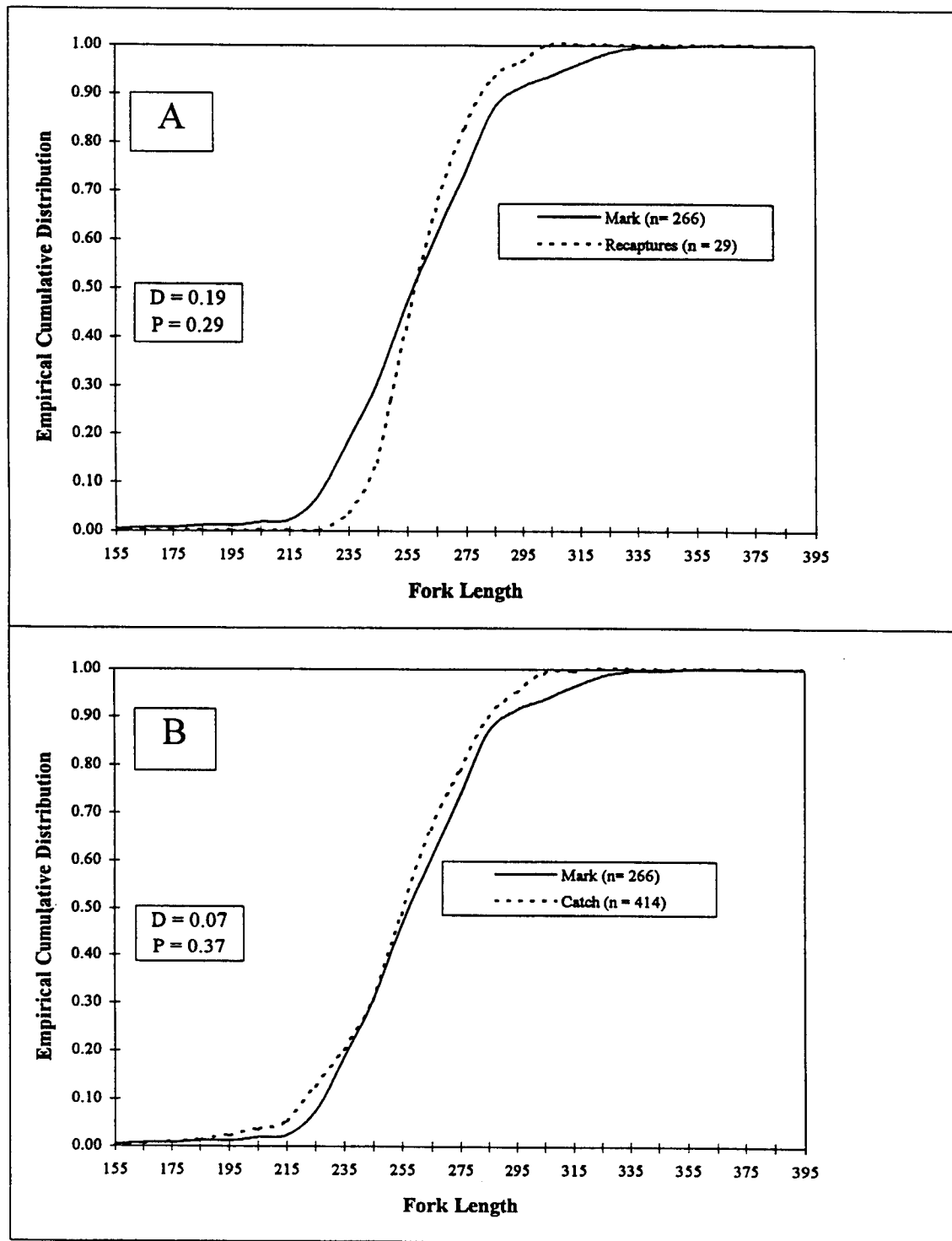


Figure 4.-Empirical cumulative distribution of lengths of Arctic grayling marked (n=266) versus lengths of Arctic grayling recaptured (n=29) in the downstream strata A) and, versus lengths of Arctic grayling examined for marks (n=414) in the downstream strata (B) in Piledriver Slough May 21-23, 1997.

Table 3.-Mark-recapture statistics by size and area for Arctic grayling in Piledriver Slough, May 12-23, 1997.

Strata {section}	Mark M	Catch C	Recap R	Capture Probability	Abundance \hat{N}	Standard Error
Upstream small fish [150-231 mm]	64	50	5	0.10	544	193
Upstream large fish [≥ 232 mm]	490	530	117	0.22	2,205	178
Total Upstream {Areas 2 and 3}	554	580	122	0.21	2,749	262
Downstream { Area 4}	266	414	29	0.07	3,680	636
Summed Area-size Stratified abundance	820	994	151	0.15	6,297	670

Table 4.-Fishery characteristics and population parameters for Arctic grayling in Piledriver Slough, 1990-1997.

Fishery Year	Fishery Status	Abundance ≥ 150 mm	Harvest (Mills)	Recruitment ^a (Age 5 fish)	Habitat ^b Assessed	Proportion ^c		Density (fish per km)	
						Ages 1-4	Ages 5+	D-hat	SE[D-hat]
1990	Open	16,435	2,380	Nd	31.0	0.54	0.46	530	45
1991	Open	17,323	3,987	5,919	34.6	0.40	0.60	500	25
1992	Open	14,030	1,030	4,540	16.1	0.42	0.58	870	115
1993	C&R ^d	10,587	759	2,639	16.1	0.51	0.49	657	84
1994	C&R	11,747	57	2,227	16.1	0.53	0.47	729	80
1995	C&R	nd	0	Nd	nd	nd	nd	nd	nd
1996	C&R	9,981	0	1,512	13.8	0.66	0.34	722	91
1997	C&R	8,660	nd	2,636	13.8	0.47	0.53	627	87
Average	----	12,680	---	3,245	---	0.50	0.50	662	75

^a The estimated abundance of age-5 fish, which is the fully recruited age at Piledriver Slough.

^b Habitat assessed refers to the number of stream kilometers that were accessible to immigrating fish and assessed.

^c The summed proportions for the age groupings and densities are calculated from past assessments (Timmons and Clark 1991, Fleming 1991, Fleming and Schisler 1993, Fleming 1994, 1995, 1997, and the present study.

^d In 1993 the fishery was open until it was closed to harvest by Emergency Order on June 26, 1993.

AGE AND SIZE COMPOSITION

Arctic grayling ranged from ages 2 to 9, with age-5 as the median and mean age. The predominant age class was age-4 (43% of the stock; Table 4) followed by age-5 (30% of the stock). In 1997, the estimated recruitment was 2,636 fish (SE = 405) that were age-5 (Figure 5), and the proportion of the assessed stock that included partially recruited age classes (ages 1-4) was 0.47 (Table 5). The size distribution of the 1997 assessed population indicated fewer small grayling were present than seen in all earlier assessments (Figure 6). The size distribution also indicated similar abundances of Arctic grayling 12 in TL (≥ 270 mm FL) or larger (previously considered as harvestable-sized). In 1997, the estimated abundance of Arctic grayling (≥ 270 mm FL) was 3,275 fish (SE = 275) while in 1996 the estimate was 2,607 fish (SE = 355).

SURVIVAL, MORTALITY, AND INDIRECT EXPLOITATION

In 1996, there were an estimated 3,376 fish (SE = 309) age 5 years and older (Figure 5). Following the 1996 catch-and-release fishery, and overwintering to 1997, it was estimated that 1,918 fish (SE = 216) age 6 years and older, or 57% (SE = 0.08), had survived. The 95% confidence interval range of the survival rate was 38 to 73%. The total instantaneous rate of mortality (Z) was -0.56.

In 1996 it was estimated that 9,981 Arctic grayling inhabited the slough by mid-June. Following the 1996 fishing season, Howe et al. (1998) estimated that 16,667 captures of Arctic grayling in Piledriver Slough resulted in 16,667 fish released, or zero harvest. The introduction of hooking mortality as a variable increased the reported harvest by a range of zero to 1,500 fish (indirect harvest). The instantaneous rate of fishing mortality (F) was calculated with Baranov's catch equation using each harvest estimate. Instantaneous fishing mortality (F) was 0.0 for the reported harvest (0 fish), and when adjusted for harvest the fishing mortality (F) was 0.20 (9% hooking mortality). Exploitation rate, or expectation of death attributable to the fishery (u), and the expectation of natural death (v) were estimated under each harvest scenario (Table 6).

DISCUSSION

During the 1997 stock assessment at Piledriver Slough, the sampling crew utilized hook-and-line sampling gear to supplement poor electrofishing catches at a location which was too deep for the wading crew to electrofish. During the marking event many fish were observed in a location near the middle of Area 4, but could not be captured. In order that a reach be effectively fished, it is necessary that either all or part-of the electrofishing crew spread laterally across the stream and fish downstream toward block nets or other electrofishers. After electrofishing the remaining adjacent waters in each sampling event, the crew returned with hook-and-line gear and captured Arctic grayling (125 fish in the first event, 141 fish in the second). The fish captured by hook-and-line were included in the mark-recapture experiment after contingency table analysis of the two gear types. A detailed examination of biases associated with hook-and-line sampling gears were not possible within the project's study design. Moreover, Piledriver Slough's size and higher than average density of Arctic grayling would make it an excellent study stream for future examinations of gear types, assessment methodologies, and validation of assumptions.

Results from the assessment study did not indicate stock rebuilding had occurred between 1996 and 1997 at Piledriver Slough, following an additional year of catch-and-release regulation. The

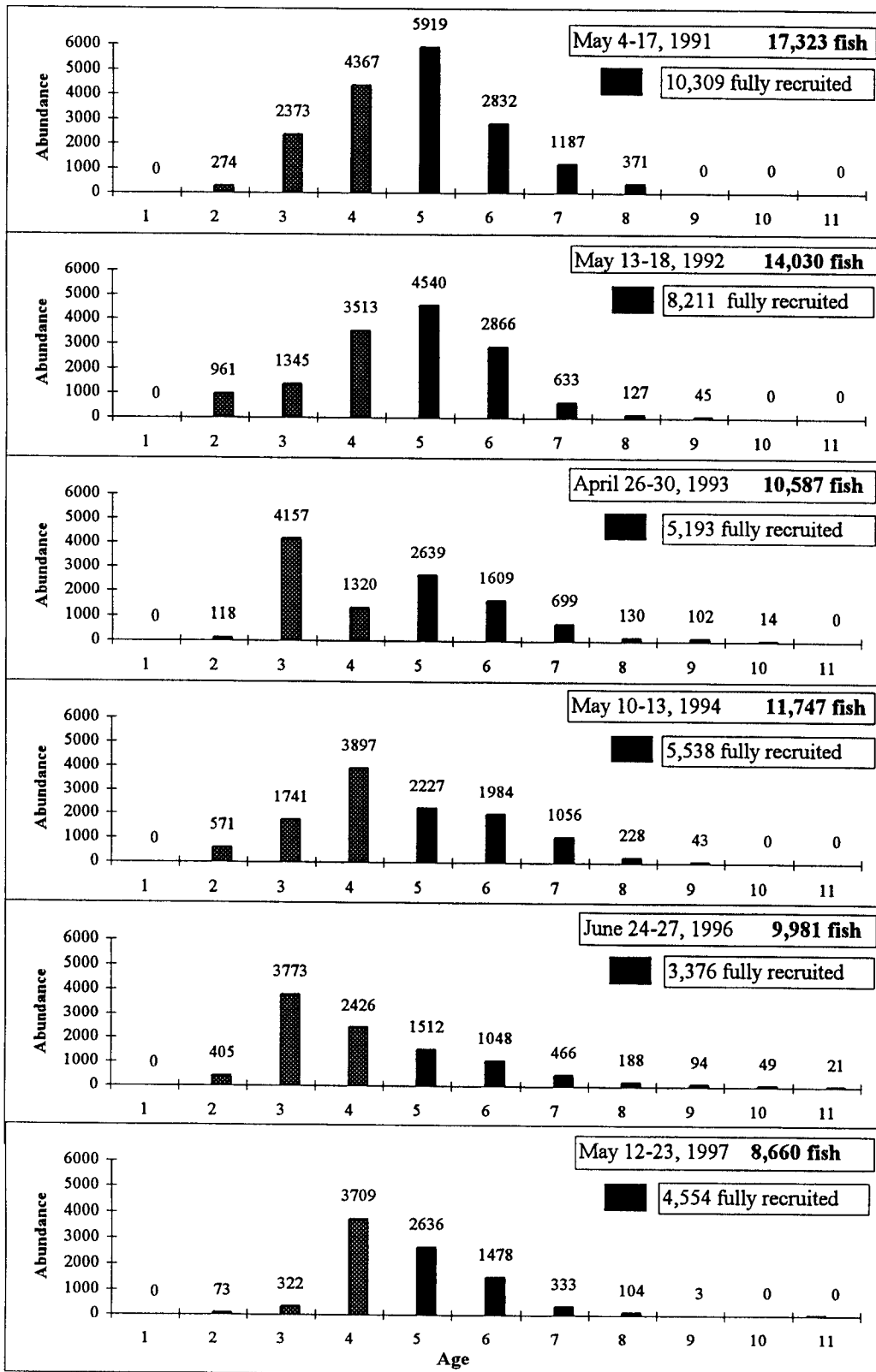


Figure 5.-Distribution of estimated abundance across age classes for Arctic grayling \geq 150 mm FL) in Piledriver Slough stock assessments between 1991 and 1997.

Table 5.-Estimates of the sampled contributions by each age class and 10 mm FL incremental size groupings for Arctic grayling (≥ 150 mm FL) captured in Piledriver Slough, May 12 – 23, 1997^a.

Age	Count ^b	\hat{P}_c	SE ^d		Length	Count ^b	\hat{P}_c	SE ^d
1	0	0.00	----		155	5	<0.01	<0.01
					165	8	<0.01	<0.01
2	7	<0.01	<0.01		175	8	<0.01	<0.01
					185	8	<0.01	<0.01
3	31	0.04	0.01		195	11	0.01	<0.01
					205	22	0.01	<0.01
4	298	0.43	0.02		215	23	0.01	<0.01
					225	79	0.06	0.01
5	259	0.30	0.02		235	122	0.08	0.01
					245	183	0.11	0.01
6	166	0.17	0.02		255	244	0.16	0.01
					265	258	0.16	0.01
7	48	0.04	0.01		275	214	0.12	0.01
					285	207	0.12	0.01
8	16	0.01	< 0.01		295	109	0.05	0.01
					305	74	0.04	0.01
9	1	< 0.01	< 0.01		315	46	0.02	<0.01
					325	19	0.01	<0.01
10	0	---	---		335	10	<0.01	<0.01
					345	4	<0.01	<0.01
11	0	---	---		355	4	<0.01	<0.01
					365	2	<0.01	<0.01
12	0	---	----		375	0	----	----
					385	1	<0.01	<0.01
					395	0	----	----
Total	826	1.00	----		Total	1,661	1.00	----

^a Age and size composition estimates were germane to the pooling of sampling events, May 12 - 23, 1997.

^b Number of sampled individuals which yielded age or size information in each age or 10 mm FL incremental size class.

^c \hat{P} = area-adjusted proportion of Arctic grayling, May 12 - 23, 1997.

^d SE = standard error of the area-adjusted proportional contribution.

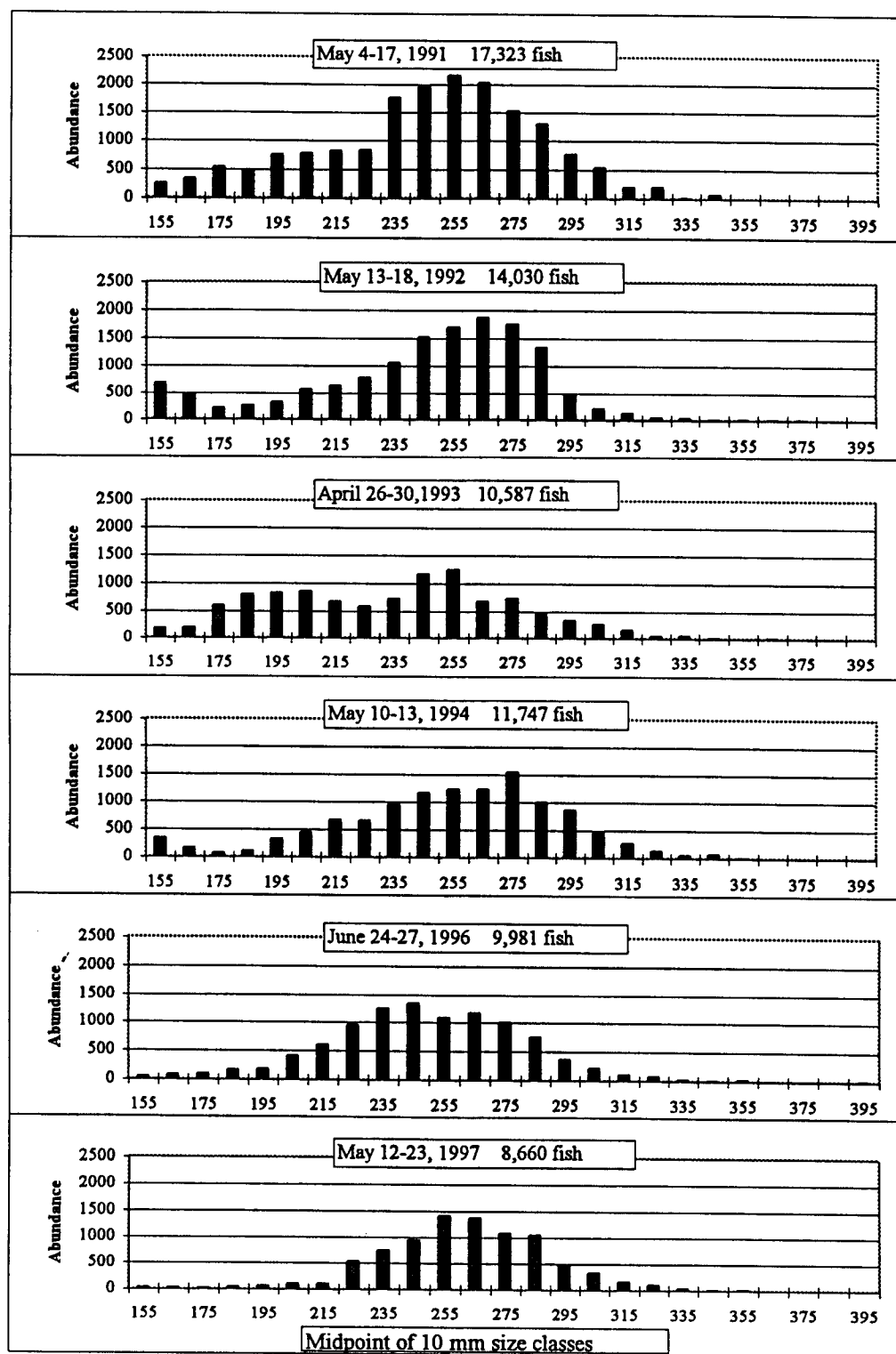


Figure 6.-Apportionment of estimated abundance across 10 mm FL incremental size categories for Arctic grayling (≥ 150 mm FL) in Piledriver Slough stock assessments between 1991 and 1997.

Table 6.-Estimates of annual fishing mortality natural mortality, and total mortality under two different hooking mortality scenarios.

Source of Mortality:	1996 Assigned Harvest Scenarios:	
	Harvest = 0	9% Hooking mortality:
	(F = 0.0):	(F = 0.20)
Fishery:	$u = 0.0$	$u = 0.18$
Natural:	$v = 0.43$	$v = 0.25$
Total:	$A = 0.43$	$A = 0.43$

1997 estimated abundance (8,660 fish \geq 150 mm FL) was similar to the 1996 estimate (9,981 fish \geq 150 mm FL), but continues to indicate a downward trend in abundance. Based on results of assumption testing, it is likely that the biases in abundance and composition were minimized by the short study duration. KS plots of fish captured in the downstream area (Figures 4A and 4B) did not indicate significant biases from immigration or emigration.. Moreover, if post-spawning behavior changes in response to the loss of summer feeding habitat by damming, assessment of the grayling stock at Piledriver Slough may become timing sensitive. In nearby Badger Slough, timing of assessment was critical in two successive years of sampling. In 1995, investigators were able to sample a total of 181 fish, in late-April and mid-May (Clark 1996). In 1996, over 1,800 Arctic grayling were sampled during early May (Ridder and Fleming *in Prep*). Angling reports and our assessment sampling has indicated the Badger Slough spawning stock returns to the Chena River soon after spawning.

Although overall abundance of Arctic grayling has declined at Piledriver Slough, the overall density of Arctic grayling has remained close to the 7-year average (Table 3) and the stock remains accessible to anglers in the lower half of the slough. It is unknown whether the loss of 50% of available habitat between 1991 and 1992 resulted in short-term adjustments to abundance through density-dependent effects, or may be carried-out over time in reductions to the stock's production of future year classes. At present the 627 fish/km density (SE= 87) of Arctic grayling in the 13.8 km area is statistically similar to densities in other years. On the other hand, estimated densities were as high as 870 fish/km (Table 3; 1992) which occurred in May 1992, shortly after beaver dams blocked-off 18.5 km of previously used habitat. It remains likely that the significant reductions in available habitat in the past five years may preclude stock rebuilding to former abundance levels.

Compositional data collected in 1997 indicate that the population's structure is generally similar to the past assessment years, only the abundance has declined. Age composition data indicated the presence of a strong age-4 year class during the 1997 assessment (Figure 6). The full strength of this year class can only be gauged when fully-recruited at age-5 in 1998. In general, the assessed population is presently comprised of 47% pre-recruited ages, which has ranged from 40 to 66% (average 50%; Fleming -unpublished data 1991-1994, 1996). Likewise, the recruiting fraction, expressed as the age-5 year class strength was 30% in 1997, and has ranged between 15 and 33% (average 27%, stdev = 0.07, CV = 29%). In contrast, recruitment levels (age-3 year class) from the Chena River are more variable and estimates have ranged between 8 and 53% of the assessed population (Clark 1996: 1987-1996 average = 26%, stdev = 0.16, CV = 61%). The greater stability of the recruiting fraction at Piledriver Slough may be related to its hydrology; the generally stable flow regime is free from high or irregular flows. In the Chena River, Clark (1992) found significant relationships between high or irregular flows during the post-hatching period and the estimated recruitment of age-3 fish three years later.

Although the composition of the 1997 population appears similar to historical averages of prerecruited age class strength and recruitment levels, future population levels may be influenced by available habitat and associated carrying capacity for Piledriver Slough brought on by habitat losses. Like abundance, estimates of the recruitment (age-5 fish) have indicated a declining trend from 1991 estimates (Table 3, and Figure 6). The estimated recruitment from 1996 and 1997 were progeny from 1991 and 1992 spawnings, when the assessed overall abundance and the

spawning component were greatest. In the 1991 population, there were an estimated 9,057 spawners, and 7,814 spawners in 1992 (D. Fleming, ADF&G-unpublished information). Although spawner-recruit relationships have not been characterized for the Piledriver Slough population, current weaknesses in the proportion of smaller and younger grayling (Figure 5: < 215 mm; Figure 6: age-2 and age-3 fish:) may indicate continued declines in recruitment.

In 1997, a higher survival rate was estimated again, after several additional years of catch-and-release regulations which began in June 1993 by Emergency Order. The current 57% estimate and 64% survival estimated from 1993 to 1994 (Fleming 1995) indicate a higher fraction of the population may have survived following the June 1993 closure to harvest:

Study Period:	Fishery:	Harvest (in Year 1 of 2)	Survival Estimate	95% Confidence Interval
1991-1992	Harvest	3,987	36%	27-44%
1992-1993	Harvest	1,030	31%	22-40%
1993-1994	Catch-and-Release	759	64%	47-81%
1994-1995	Catch-and-Release	57	nd	Nd
1995-1996	Catch-and-Release	0	nd	Nd
1996-1997	Catch-and-Release	0	57%	38-73%

The estimated survival from 1996 to 1997 reflects a combination of natural mortality and incidental hooking mortality losses to the assessed stock. This assessment at Piledriver Slough represents the first opportunity to estimate *natural* survival and mortality under catch-and-release regulations. Since no additional losses of habitat occurred between 1996 and 1997 at Piledriver Slough, the estimates used to describe overall and natural mortality of the assessed population of grayling may be accurate. The estimated annual rate of natural mortality (ν) was 43%, which is similar to levels estimated for Arctic grayling in the Chena River (31%: five-year average for 1991-1995) also under catch-and-release regulations (Clark 1996). It should be noted that these are maximum estimates, since incidental hooking mortalities occur, are not reported, and rarely are included in estimation of dynamic rates.

The effect of catch-and-release management at Piledriver Slough on the exploitation rate was estimated indirectly. A range of realistic probabilities of hooking mortalities were applied to catch estimates from the 1996 fishery (Howe et al. 1998) to estimate acute or latent deaths attributable to hooking injuries. After assigning a 5% or 9% probability of hooking mortality the indirect exploitation rate by angling ranged between 10 and 18%. These estimates from the catch-and-release Arctic grayling fishery at Piledriver Slough indicate that sustainability and adherence to the Piledriver Slough Fishery Management Plan (ADF&G- *Unpublished*) will be most possible through continued catch-and-release regulation of the grayling fishery. In December 1997, the Alaska Board of Fish adopted Department proposed changes to a permanent catch-and-release regulation, while adding additional gear restrictions to allow only the use of

single-hook artificial lures. If a consumptive fishery for Arctic grayling is desired in the future, it will be important to accurately determine hooking mortality rates so that surplus production can be determined.

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LITERATURE CITED

- Bailey, N. T. J. 1951. On estimating the size of mobile populations from capture-recapture data. *Biometrika* 38:293-306.
- Bailey, N. T. J. 1952. Improvements in the interpretation of recapture data. *Journal of Animal Ecology* 21:120-127.
- Brown, C. J. D. 1943. Age and growth of Montana grayling. *The Journal of Wildlife Management* 7:353-364.
- Clark, R. A. 1996. Stock status and rehabilitation of Chena River Arctic grayling during 1995. Alaska Department of Fish and Game, Fishery Data Series No. 96-2, Anchorage.
- Darroch, J. N. 1961. The two-sample capture-recapture census when tagging and sampling are stratified. *Biometrika* 48:241-260.
- Fleming, D. F. 1991. Stock assessment of Arctic grayling in Piledriver Slough, 1991. Alaska Department of Fish and Game, Fishery Data Series No. 91-71, Anchorage.
- Fleming, D. F. and G. J. Schisler 1993. Stock assessment of Arctic grayling and rainbow trout in Piledriver Slough during 1992. Alaska Department of Fish and Game, Fishery Data Series No. 93-8, Anchorage.
- Fleming, D. F. 1994. Stock assessment of Arctic grayling and rainbow trout in Piledriver Slough during 1993. Alaska Department of Fish and Game, Fishery Data Series No. 94-34, Anchorage.
- Fleming, D. F. 1995. Stock assessment of Arctic grayling in Piledriver Slough during 1994. Alaska Department of Fish and Game, Fishery Data Series No. 95-15, Anchorage.
- Fleming, D. F. 1997. Stock assessment of Arctic grayling in Piledriver Slough during 1996. Alaska Department of Fish and Game, Fishery Data Series No. 97-18, Anchorage.
- Goodman, L. A. 1960. On the exact variance of a product. *Journal of the American Statistical Association*, Vol 55:708-713.
- Howe, A. L., G. Fidler, and M. J. Mills. 1995. Harvest, catch, and participation in Alaska sport fisheries during 1994. Alaska Department of Fish and Game, Fishery Data Series Number 95-24, Anchorage.
- Howe, A. L., G. Fidler, A. E. Bingham, and M. J. Mills. 1996. Harvest, catch, and participation in Alaska sport fisheries during 1995. Alaska Department of Fish and Game, Fishery Data Series Number 96-32, Anchorage.
- Howe, A. L., G. Fidler, A. E. Bingham, C. Olness, and M. J. Mills. 1997. Harvest, catch, and participation in Alaska sport fisheries during 1995. Alaska Department of Fish and Game, Fishery Data Series Number 97-29, Anchorage.

LITERATURE CITED (Continued)

- Kruse, T. E. 1959. Grayling of Grebe Lake, Yellowstone National Park, Wyoming. U.S. Fish and Wildlife Service Fishery Bulletin 59:307-351.
- Mills, M. J. 1984. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1983-1984. Project F-9-16, 25(SW-1-A): 122 pp.
- Mills, M.J. 1988. Alaska statewide sport fisheries harvest report. Alaska Department of Fish and Game, Fisheries Data Series No. 52, Juneau.
- Mills, M. J. 1989. Alaska statewide sport fisheries harvest report. Alaska Department of Fish and Game, Fisheries Data Series No. 122, Juneau.
- Mills, M. J. 1990. Harvest and participation in Alaska sport fisheries during 1989. Alaska Department of Fish and Game, Fishery Data Series No. 90-44, Anchorage.
- Mills, M. J. 1991. Harvest, catch, and participation in Alaska sport fisheries during 1990. Alaska Department of Fish and Game, Fishery Data Series Number 91-58, Anchorage.
- Mills, M. J. 1992. Harvest, catch, and participation in Alaska sport fisheries during 1991. Alaska Department of Fish and Game, Fishery Data Series Number 92-40, Anchorage.
- Mills, M. J. 1993. Harvest, catch, and participation in Alaska sport fisheries during 1992. Alaska Department of Fish and Game, Fishery Data Series Number 93-42, Anchorage.
- Mills, M. J. 1994. Harvest, catch, and participation in Alaska sport fisheries during 1993. Alaska Department of Fish and Game, Fishery Data Series Number 94-28, Anchorage.
- Seber, G. A. F. 1982. The estimation of animal abundance and related parameters, second edition. Charles Griffin and Company, Limited, London.
- Tack, S. L. 1980. Migrations and distributions of Arctic grayling *Thymallus arcticus* (Pallas), in Interior and Arctic Alaska. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1979-1980. Project F-9-12, 21(R1). 32 pp.
- Timmons, L. S. 1992. Evaluation of the rainbow trout stocking program for Piledriver Slough, 1991. Alaska Department of Fish and Game, Fishery Data Series No. 92-5, Anchorage.
- Timmons, L. S., and R. A. Clark. 1991. Stock status of Piledriver Slough Arctic grayling. Alaska Department of Fish and Game, Fishery Data Series No. 91-37, Anchorage.
- Wojcik, F. J. 1955. Life history and management of the grayling in interior Alaska. M.S. Thesis, University of Alaska, Fairbanks. 54 pp.

APPENDIX A

Appendix A1.-Methods for detection of gear selectivity and bias reduction.

Result of first K-S test ^a	Result of second K-S test ^b
<u>Case I^c</u>	
Fail to reject H_0	Fail to reject H_0
Inferred cause: There is no size-selectivity during either sampling event.	
<u>Case II^d</u>	
Fail to reject H_0	Reject H_0
Inferred cause: There is no size-selectivity during the second sampling event, but there is during the first sampling event	
<u>Case III^e</u>	
Reject H_0	Fail to reject H_0
Inferred cause: There is size-selectivity during both sampling events.	
<u>Case IV^f</u>	
Reject H_0	Reject H_0
Inferred cause: There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown.	

^a The first K-S (Kolmogorov-Smirnov) test is on the lengths of fish marked during the first event versus the lengths of fish recaptured during the second event. H_0 for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish recaptured during the second event.

^b The second K-S test is on the lengths of fish marked during the first event versus the lengths of fish captured during the second event. H_0 for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish sampled during the second event.

^c Case I: Calculate one unstratified abundance estimate, and pool lengths and ages from both sampling event for size and age composition estimates.

^d Case II: Calculate one unstratified abundance estimate, and only use lengths and ages from the second sampling event to estimate size and age composition.

^e Case III: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Pool lengths and ages from both sampling events and adjust composition estimates for differential capture probabilities.

^f Case IV: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Also calculate a single abundance estimate without stratification.

If stratified and unstratified estimates are dissimilar, discard unstratified estimate and use lengths and ages from second event and adjust these estimates for differential capture probabilities.

If stratified and unstratified estimates are similar, discard estimate with largest variance. Use lengths and ages from first sampling event to directly estimate size and age compositions.